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Flashover Characteristics of a Single-wave Voltage of Commercial Frequency in Air Gap Spacings

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Abstract

The investigation is made on the flashover characteristics of a single-wave voltage of commercial frequency in the air gap spacings of 6.25 cm-diameter spheres. The wave form of voltage is a single half of AC sine wave of 50 Hz obtained by controlling a thyristor on the primary side of a testing transformer. Particularly, it is noticeable that, without irradiation of the gap, the Volt-time characteristics take V-type for positive polarity.

1. Introduction

Because of stepping up operating voltages in the EHV (extra high voltage) transmission systems, insulation design based on lightning surges has been replaced recently by that based on switching surges. But, when circuit breakers are closed, for example, on short transmission lines where surges can not propagate as so-called surges, in forced transmissions or reclosings when transmission lines are faulty, in charging lines at rated voltages, and so on, switching surges have various forms depending on the phases of voltages.

What is aimed in this paper is shown as follows:

(1) With respect to the first half-sine-wave of AC voltage in circuit breakers being closed at zero-phase of voltage, the flashover characteristics are investigated. Besides, this investigation proves to be significant for the stand-by experiment of zero-voltage closing and zero-current breaking[(1),(2)].

Then, it is possible to investigate in the last step to what extent switching surges are reduced by controlling the phases of voltages in circuit breakers being closed on simulated transmission lines.

(2) An examination is made of the relation concerning flashover between alternating voltage and a single-wave voltage of commercial frequency.

2. Method of Test

A testing circuit is shown in Fig. 1. AC voltage of commercial frequency

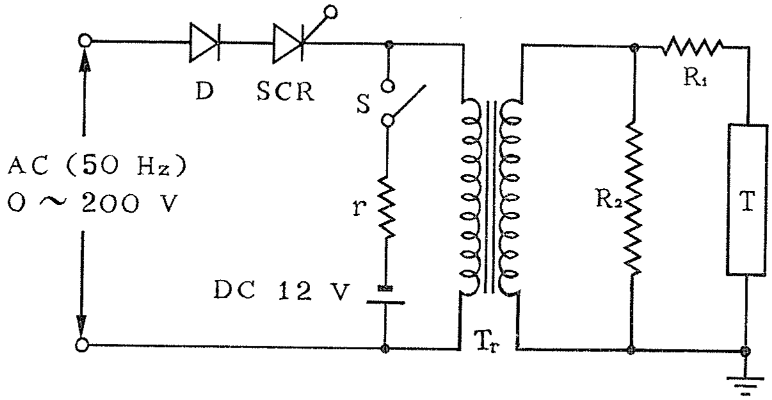


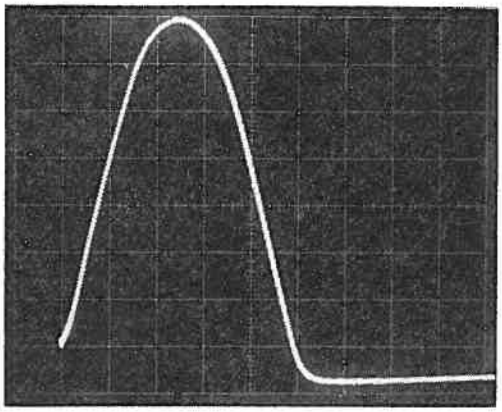
Fig. 1 Testing circuit

(50 Hz) is used as a power source. In Fig. 1, **SCR** is a thyristor, **D** a protective diode for SCR, **r** a resistor controlling DC for opposite excitation(3), **S** a switch, $\mathbf{T_r}$ a testing transformer and $\mathbf{R_1}$ a discharge resistor. Resistor $\mathbf{R_2}$ makes the phase difference between the primary voltage and the current through **SCR** as small as possible and also damps natural oscillation in a testing circuit at the same time. **T** is a tested sample, for which the 6.25 cm-diameter sphere gap is used.

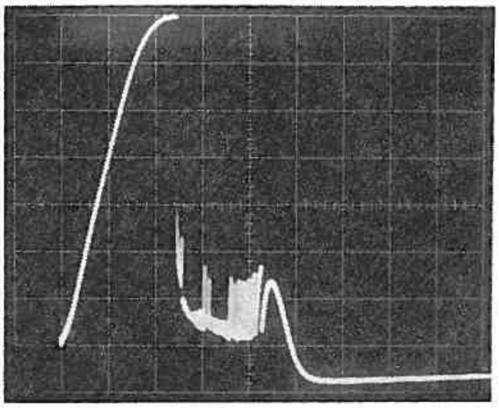
SCR is turned on with the help of its gate control circuit(4) at the supply voltage of nearly zero and turned off when the current through SCR is zero after 10 ms, half a cyele of 50 Hz.

A single-wave voltage of commercial frequency always magnetizes the iron core of a testing transfomer in the same direction, and then SCR can not be well controlled under the influence of the residual magnetism and the magnetic saturation. The wave form of voltage is distorted and the current through SCR does not become zero even after 10 ms. In order to take off the residual magnetism and the magnetic saturation, DC excitation is equipped in the opposite direction of AC one on the primary side of a testing transformer. Consequently, SCR is well turned off, when S must be switched on before every test. In this way a single-wave voltage of commercial frequency appears on its secondary side. The wave forms —— the full wave in a) and the chopped one in b) —— are shown in Fig. 2.

Flashover voltages are divided by a potential divider of resistance type and measured by a cathode ray oscilloscope. All the data are revised for the relative air densities.



a) The full wave



b) The chopped wave

Fig. 2 The wave forms of a single-wave voltage of commercial frequency (5360 V/div, 2 ms/div)

3. Results and Discussions

JEC-172 recommends that, when gap spacings are within half diameters of speres, sphere gaps form uniform electric fields and errors in measuring are within $\pm 3\%$, but that irradiation of the gaps by radioactive or ultraviolet rays should be used when voltages below 50 kV (peak) are measured or sphers less than 12.5 cm-diameter are used.

A single-wave voltage is an impulse one, because it is of a single wave and of mono-polarity. Since it is, however, a super long wave-front voltage whose time to crest is 5 ms, whether it has impulsive or DC characteristics is an important problem for analysis of characteristics in case that wave-front durations are aimed at.

The results of experiments on the 6.25 cm-diameter sphere gap are shown in the following subsections.

3.1. Minimum flashover voltage characteristics

When the 50% flashover voltages are measured without irradiation of the gap by ultraviolet rays, disorder of flashover is notable and it is not easy to measure the 50% flashover voltages. This is an impulsive characteristic. It means that AC flashover takes place at constant value of voltage not because the wave form is very gentle but because the much humped characteristic of AC voltage increases the probability for appearance of flashover without ions and electrons supplied forcedly. On the other hand, with irradiation of the gap by ultraviolet rays, the flashover of a single-wave voltage of commercial frequency takes place either always or not at all, and its behavior is similar to that of DC voltage. Therefore irradiation of the gap should be used in messuring a single-wave voltage of commercial frepuency as well as other im-

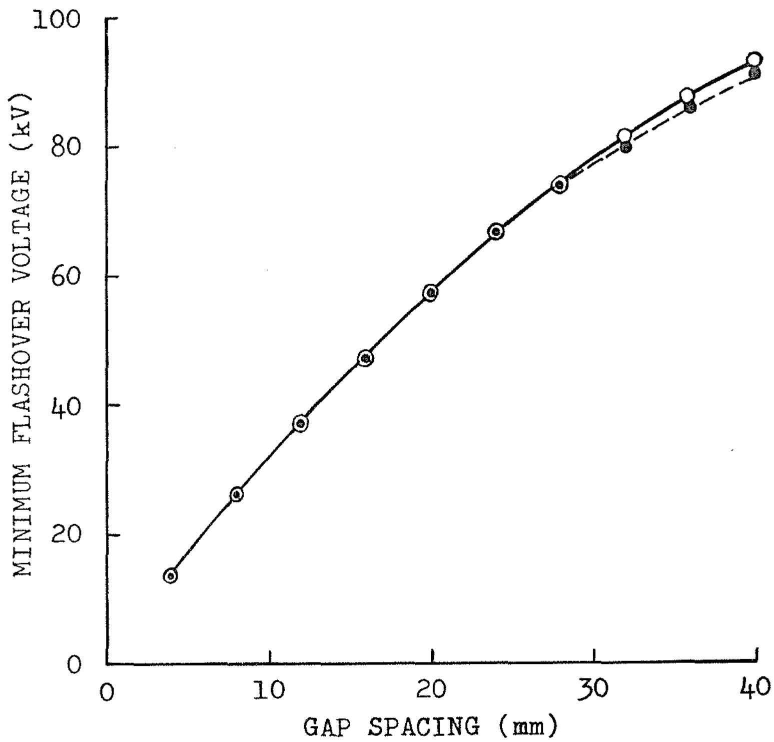


Fig. 3 The minimum flashover characteristics for positive (○) and negative (●) polarities pulse ones. This is the reason why the minimum flashover voltage has been adopted instead of the 50% one.

The minimum flashover characteristics for positive and negative polarities are shown in Fig. 3. Both of them are mutually equal when the gap spacing is up to about 30 mm, but the positive flashover voltages are higher than the negative ones when over 30 mm as well as DC and other impulse voltages.

The effect of irradiation is great in all gap spacings for positive polarity but little in larger gap spacings for negative polarity because only the negative flashover voltage has an inclination to keep almost constant value in each gap spacing over 30 mm even without irradiation.

3.2. Volt-time characteristics

Without irradiation, the V-t (Volt-time) characteristics scatter on account of notable disorder of flashover for both polarities, but an envelope of the minimum flashover points at respective time to flashover takes clearly V-type for positive polarity (Fig. 4). The V-type characteristic, which has been observed in non-uniform electric field region until now[(5),(6)], is observed in uniform electric field. This can be considered to be very interesting and important. On the other hand, for negative polarity, flashover voltages are higher as a whole and time lag of flashover is remarkable in case of overvoltages, but the characteristic does not take V-type (Fig. 5).

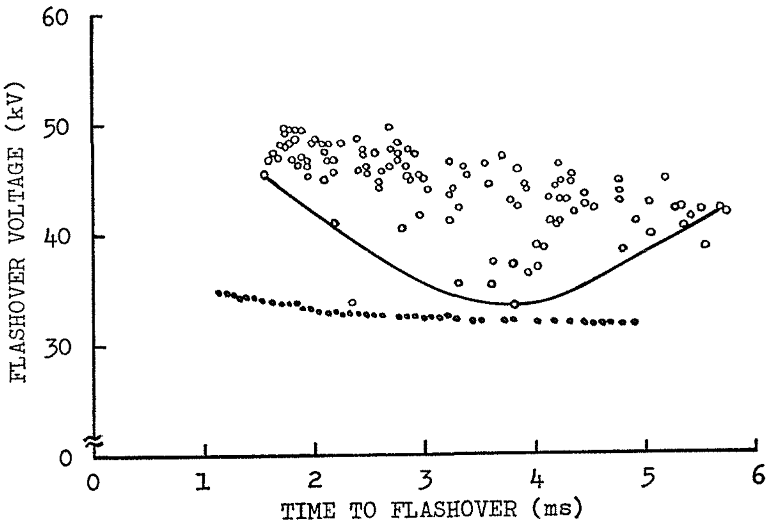


Fig. 4 The Volt-time characteristics for the gap spacing of 10 *mm* for positive polarity with (●) and without (○) irradiation

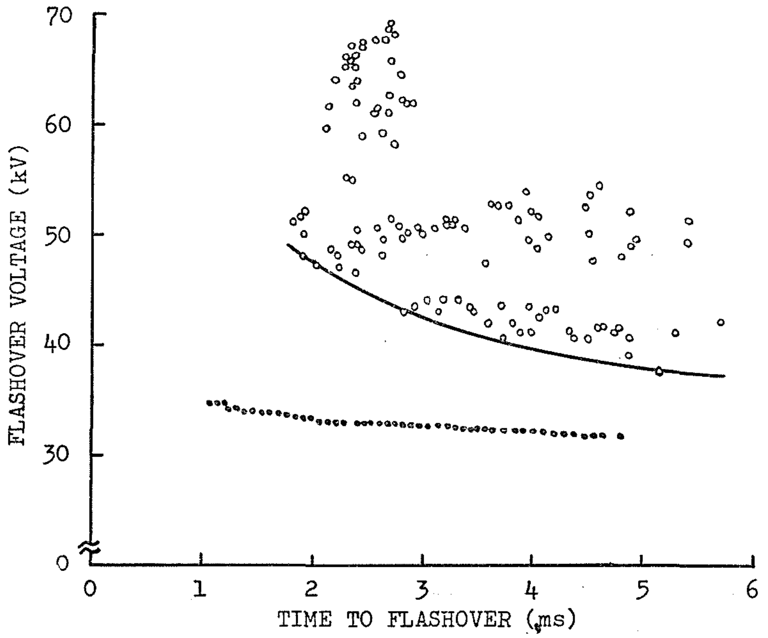


Fig. 5 The Volt-time characteristics for the gap spacing of 10 *mm* for negative polarity with (●) and without (○) irradiation.

With irradiation, flashover points are all located on the part of wave-front and also flashover voltages drop uniformly. The V-t characteristics are the same and form straight lines in gap spacings from 10 to 20 mm for both polarities. They are the characteristics themselves in uniform electric field and no problem is found in them. Therefore, in this case, the effect of irradiation is greater for negative polarity than that for positive one. The positive characteristics with irradiation are shown in Fig. 6, but the negative ones are not.

3.3. AC flashover tests

It is generally considered that AC flashover voltage can not drop by means of irradiation of the gap by ultraviolet rays. But also in AC flashover tests, irradiation of the gap helps the flashover voltages to drop (Fig. 7). The difference between flashover voltages with irradiation and those without irradiation becomes conspicuous in gap spacings over 12 mm.

In this paper, AC flashover voltages are not compared with those of a single-wave voltage of commercial frequency because of a few dubious points.

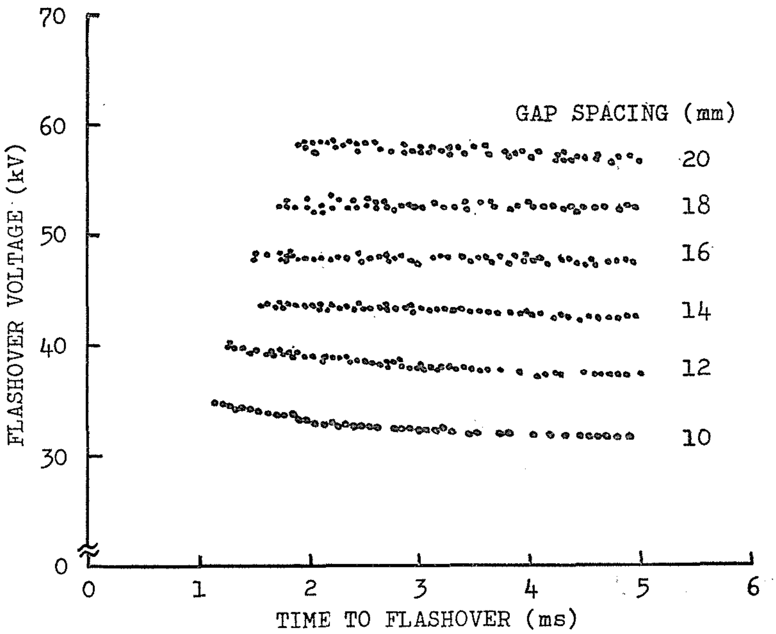


Fig. 6 The Volt-time characteristics for gap spacings from 10 to 20 *mm* for positive polarity with irradiation.

4. Conclusions

In conclusion, the flashover characteristics of a single-wave voltage of commercial frequency in the 6.25 cm-diameter sphere gap are shown as follows:

(1) Time lag and disorder of flashover are remarkable without irradiation. This is an impulsive characteristic, and irradiation of the gap should be used in measuring the voltages. It means that the much humped characteristic of AC voltage keeps AC flashover voltage almost constant in each gap spacing.

(2) There are differences between the minimum flashover voltages for positive polarity and those for negative polarity in gap spacings over 30 mm.

(3) The V-t characteristic takes V-type for positive polarity without irradiation.

(4) The V-t characteristics form straight lines for both polarities with irradiation.

(5) Of the 50% flashover voltage, the effect of irradiation is greater for positive polarity that for negative polarity, and of the V-t characteristics, it is greater for negative polarity than that for positive polarity.

(6) AC flashover voltages drop with irradiation.

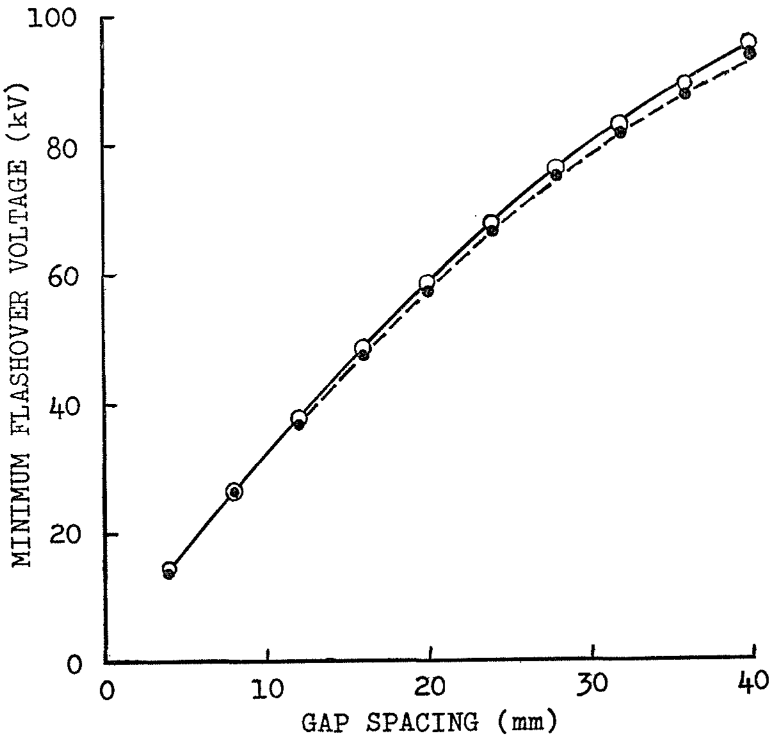


Fig. 7 The minimum flashover voltage characteristics of alternating voltagewith(●)and without(○) irradiation.

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気中ギャップにおける単発商用周波電圧のフラッシオーバ特性

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直径6.25 cm の気中球ギャップにおける単発商用周波電圧のフラッシオーバ特性を，正負両極性について求めた。電圧波形は交流 50 Hz 正弦波電圧の単発半波であり，試験用変圧器の一次側をサイリタスで制御することによって得られる。特に，非照射時の V-t 特性が正極性でV形になるということが注目に値する。